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VERIFICATION OF THE EFFECT OF LATERALITE ON SOIL STABILIZATION FOR HIGHWAY CONSTRUCTION

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Abstract: Constant rise in price of cement and other binders have caused a constant surge in cost of construction, rehabilitation and maintenance of roads. This study is an attempt to verify the effect of soil stabilization using a chemical stabilizer (lateralite) which is locally produced in Nigeria. Lateralite was used to stabilize two selected soil samples purposely to improve and proffer sustainable subgrade, subbase and base course materials for highway pavement based upon recommended practice of American Association of State Highway and Transportation Officials (AASHTO) classification system. Cement and lime were also used to stabilize the two soil samples, and then the results of the three stabilizers were compared. The first soil sample utilized is a clayey soil material with group classification of A-7-6 whilst the second soil sample was bentonite, a highly plastic swelling clay. Varying percentages of the three stabilizers from 2% to 10% were mixed with the two soil samples. Values obtained before addition of any stabilizer to the A-7-6 lateritic soil and bentonite are MDD of 1.47kN/m^3 and 1.15kN/m^3; OMC of 19.20% and 38.10%; unsoaked CBR of 8% and 3%; soaked CBR of 6% and 1%; cured unconfined compressive strength of 290 kN/m^2 and 46.5 kN/m^2 respectively. Values obtained after addition of 10% lateralite to A-7-6 lateritic soil and bentonite resulted in MDD of 1.42kN/m^3 and 1.06kN/m^3; OMC of 24.00% and 41.50%; soaked CBR of 19.8% and 3.8%; unsoaked CBR of 48.8% and 6.8%; cured unconfined compressive strength of 422 kN/m^2 and 64.4 kN/m^2 respectively. In all the tests considered for the A-7-6 soil, cement stabilization had the best results and would be most effective in stabilizing this soil. It is followed by the lime stabilization and laterilite was third. However, in the stabilization of the bentonite, there is no significant difference in the results of the three stabilizers; Therefore, laterilite could substitute for cement or lime. Lateralite should be considered for the stabilization of swelling and other very poor soils where cement stabilization would be uneconomical.

Keywords: lateralite, cement, lime stabilization, bentonite, lateritic soil

1. INTRODUCTION

A lot of laterite gravels and pisoliths, which are good for gravel roads occur in tropical countries of the world, including Nigeria (Osinubi and Badeh, 1994). There are instances where lateritic soils may contain substantial amount of clay minerals that its strength and stability cannot be guaranteed under load, especially in the presence of moisture. These types of lateritic soils are also common in many tropical regions including Nigeria where in most cases sourcing for alternative soil may prove economically unwise but rather to improve the available soil to meet the deserved objective (Mustapha, 2005). Over the times, cement and lime are the main materials used for stabilizing soils. These materials have rapidly increased in price due to the sharp increase in the cost of energy source since the 1970s (Neville, 2000). Ola (1983) reported that laterite is a soil formed by the concentration of hydrated oxides of iron and aluminum with the ratio of silica (SiO_2) to sesquioxides ($Fe_2O_3 + Al_2O_3$) of less than 1.33, while the between 1.33 and 2.0 are indicative of lateritic soil and those greater than 2.0, non- lateritic soil. Laterite formation factors include climate (precipitation, leaching, capillary rise and temperature), topography (drainage), vegetation, parent rock (iron rich rocks) and time, of these primary factors; climate is considered to be the most important (Ola, 1978).

Bentonite is a naturally occurring clay with high expansion capability and low permeability. Two types of commercially available bentonites are, sodium bentonite and calcium bentonite (Chinju and Hashmi, 2016). According to Ojuri and Oluwatuyi (2017), bentonite is a pure mineral clay consisting mostly of montmorillorite. Bentonite has high swelling potential and low hydraulic conductivity (Glearon et al., 1997). Lateralite is a chemical stabilizer locally produced in Nigeria and it is a mineral compound selected in definite proportions and pulverized to the fineness of cement to induce pozzolanic effect on sesquioxides rich lateritic soils in general. The sesquioxide minerals in the soil are noted to form a new precipitate with laterilite. Laterilite is currently being used in Nigeria to stabilize very poor soils. Meshida et al., (2011). Carried out a comparative study of Portland Cement, Hydrated Lime and Lateralite as Stabilizaing Agents of Quaternary Coastal Plain Sands North of Lagos Metropolis in Nigeria and as Road Construction Material. The Lagos end of the Lagos-Ibadan expressway was constructed on the wetland terrain of South Western Nigeria. The substandard geotechnical properties of the soil required improvement through stabilization by additives. The study examined the effect of three fluxes namely Portland cement, Hydrated Lime and Lateralite on the strength tests on several samples of the soil deposit. It was discovered that Lateralite offered the highest hope of stabilizing the deposit effectively for highway construction.

2. MATERIALS

Sample of the A-7-6 lateritic soil was excavated from Latitude 7°47'21.9"N and Longitude 5°14'54.67". It is an existing burrow pit, along Ifaki-Iworoko road, behind Hajaig Construction Company project office, Ifaki, Ekiti State in Nigeria. The bentonite sample was obtained from Pascal Science Ltd. in Akure Ondo state in Nigeria. Bentonite Clay, also known as aluminium phyllosilicate is an absorbent clay richly composed of montmorillonite and beidellite formed as a result of the decomposition of volcanic ash mainly in the presence of water. There are three types of bentonites; sodium bentonite, calcium bentonite, and potassium bentonite; of which only sodium and calcium bentonites are used for industrial purposes.. The type of cement used for this experiment is Elephant Portland Limestone cement (Lafarge brand) with grade 42.5 which was obtained from a market in Ado-Ekiti, Ekiti state Nigeria. Lime in soil stabilization can be in form of quicklime (calcium oxide), hydrated lime (calcium hydroxide), or lime slurry. Quicklime is obtained through chemical transformation of calcium carbonate (limestone) into calcium oxide. Hydrated lime is created from reaction of quicklime and water, while lime slurry is suspension of hydrated lime in water. Hydrated lime was used for this research and potable water was obtained from a borehole.

3. METHODS

Methods employed include field sampling operation during which samples of lateritic soil were collected. The basic index and engineering properties of soil were determined following the procedures as stipulated by BS1377 (1990).

Preliminary tests such as atterberg limits test, particle size distribution test and specific gravity tests were carried out on these samples to determine their index properties. The soil sample and bentonite were later separately treated with 2%, 4%, 6% and 10% of stabilizing agents (cement, lime and lateralite). The effects of each of the admixtures on the engineering properties of the two soils were determined. Such properties include: compaction, California bearing ratio and unconfined compressive strength tests. For this study, only Standard Proctor compactive effort was used.

4. RESULTS AND DISCUSSION

— Chemical Constituents of materials used

The chemical constituents of the materials used namely; cement, lime, lateralite, A-7-6 soil and bentonite are shown in Table 1 below.

Table 1. Chemical components of Cement, Lime, Lateralite, A-7-6 Soil and Bentonite

Compound	Cement	Lime	Lateralite	A-7-6 Soil	Bentonite
Silicon oxide (%)	21.7	1.57	60.42	59.89	58.44
Aluminum oxide (%)	5.75	0.52	36.44	32.42	21.90
Ferric oxide (%)	2.50	0.02	0.052	0.058	2.53
Calcium oxide (%)	65.20	67.20	1.67	2.02	0.93
Magnesium oxide (%)	1.80	1.30	0.70	0.57	2.51
Manganese oxide (%)	-	0.08	0.03	0.42	1.28
Potassium oxide (%)	0.5	0.05	0.07	0.13	1.19
Sodium oxide (%)	0.41	0.04	0.064	0.27	2.40

The ordinary Portland cement contains 65.20% of CaO, 2.5% of Fe_2O_3, 5.75% of Al_2O_3, 21.7% of SiO_2, 1.80% of MgO, 0.5% K_2O, 0.41% of Na_2O. From these values the cement used for this study met the requirements as stipulated by NIS 367(1997) and NIS 368-2(1990). The chemical composition of the hydrated lime showed that SiO_2 was 1.57%, Al_2O_3 was 0.52%, Fe_2O_3 was 0.02%, CaO was 67.20%, MgO was 1.30%, these are the active ingredients whose values fall within the range for hydrated lime (Joel and Edeh, 2015).

The chemical composition of lateralite showed that SiO_2 was 60.42%, Al_2O_3 was 36.44%, Fe_2O_3 was 0.052%, CaO was 1.67%, MgO was 0.70%, MnO was 0.03%, K_2O was 0.07% and Na_2O was 0.064%, this met the requirements as outline by Akiije (2016). A-7-6 soil sample showed that SiO_2 was 59.89%, Al_2O_3 was 32.42%, Fe_2O_3 was 0.058%, CaO was 2.02%, Mg was 0.42%. To confirm if the soil was lateritic, ratio of SiO_2 to the addition of Al_2O_3 and Fe_2O_3, $\frac{SiO2}{Al_2+Fe_2O_3}$ =1.84, this confirms that the soil sample is a lateritic soil (Ola, 1983).

The chemical composition of bentonite showed that SiO_2 was 58.44%, Al_2O_3 was 21.90%, Fe_2O_3 was 2.53%, CaO was 0.93%, MgO was 2.51% and Na_2O was 2.40%, these values adequately met the requirements for sodium bentonite (Ojuri and Oluwatuyi 2017).

5. PRELIMINARY TEST RESULTS

Table 2 shows the preliminary results of the index properties of the natural A-7-6 soil sample and the bentonite. The moisture content of the natural soil sample was 22.6% while its specific gravity was 2.68. 64% of the soil passed through BS Sieve No 200. (Figure 1). The liquid limit is 42.2%, and the plasticity index is 17.6%. This places the soil in A-7-6 category in the AASHTO method of soil classification and CL in the Unified Soil classification System (USCS). Similarly, for the bentonite, result of sieve analysis showed that 85% of the air dried material passed through BS No 200 sieve. The liquid limit was 229%, while the plastic limit was 89%. The plasticity index (PI) of bentonite which was 140%, The natural moisture content and specific gravity of the bentonite sample was 15.2% and 2.30 respectively, these values place the soil in the A-7-5 category in the AASHTO method of soil classification and CH in the Unified Soil Classification System.

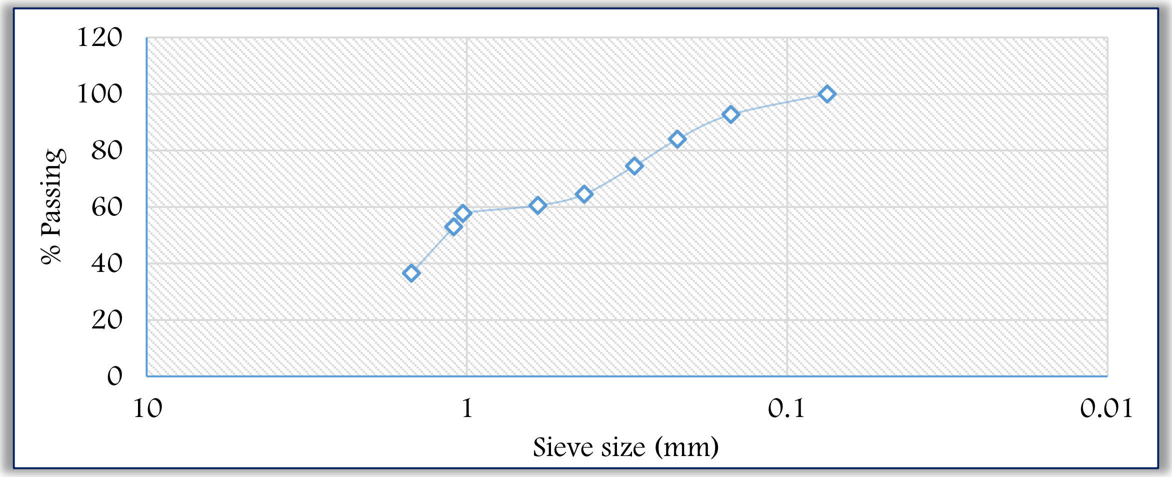

Figure 1: Plot of Sieve Analysis Curve for A-7-6 Soil.

Table 2: Index Properties of A-7-6 Soil and Bentonite

Properties	A-7-6 Soil	Bentonite
Natural Moisture content (%)	22.6	15.2
Specific Gravity	2.68	2.38
Percentage passing BS sieve No 200	64.5	85
Liquid limit (%)	42.2	229
Plastic limit (%)	24.6	89
Plasticity Index (%)	17.6	140
AASHTO classification	A-7-6	A-7-5
Unified Soil Classification System (USCS)	CL	CH
Maximum Dry Density (kN/m^3)	1.47	1.15
Optimum Moisture Content (%)	19.20	38.1
California Bearing Ratio (Unsoaked) (%)	8	3
California Bearing Ratio (Soaked) (%)	6	1
Unconfined Compressive Strength (kN/m^2)	290	46.5
Color	Reddish brown	Cream

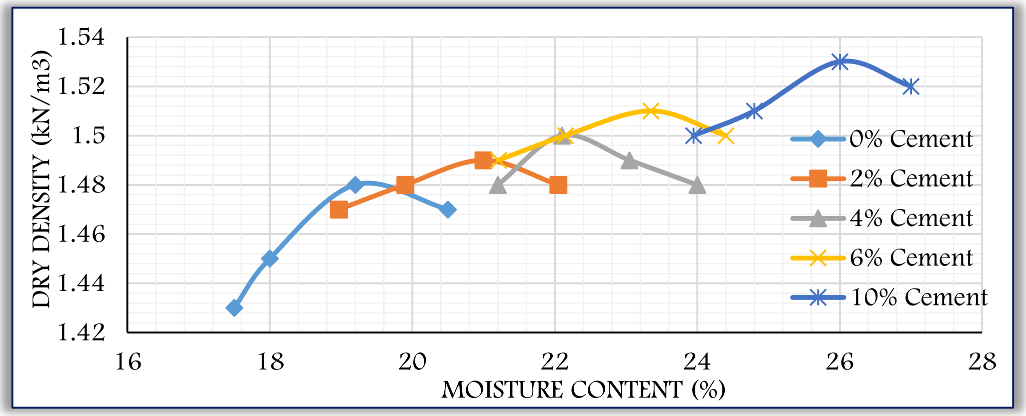

Figure 2: Compaction Characteristic Curves for Stabilized A-7-6 Soil with Cement

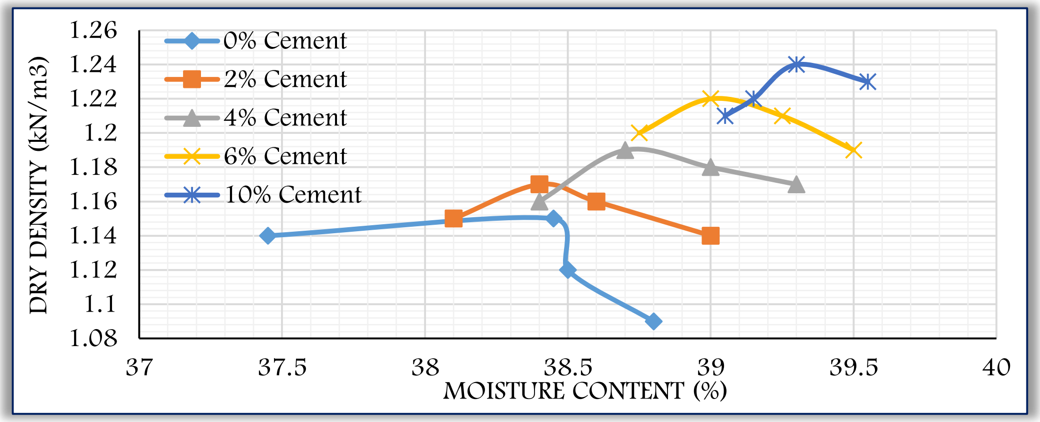

Figure 3: Compaction Characteristic Curves for Stabilized Bentonite with Cement

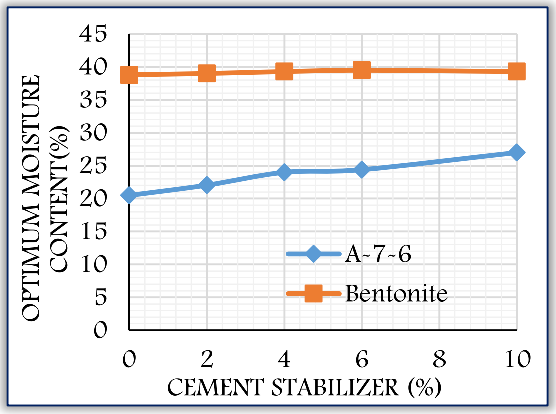

Figure 4: Variation of Optimum Moisture Content (OMC) with Cement Content

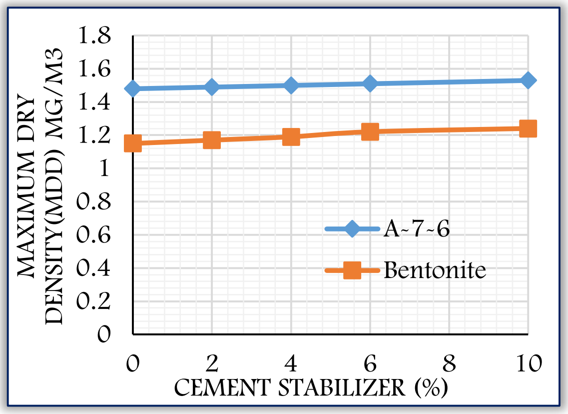

Figure 5: Variation of MDD with Cement Content

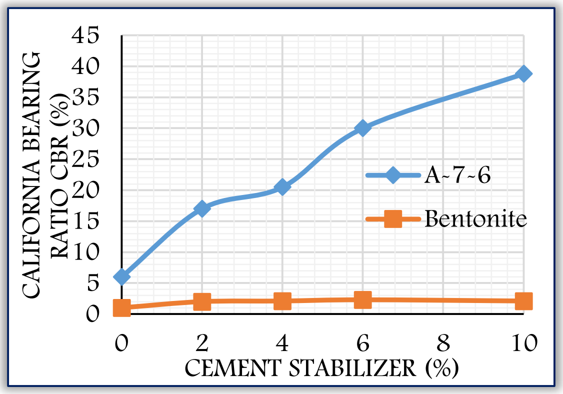

Figure 6: Variation of Soaked CBR with Cement Content

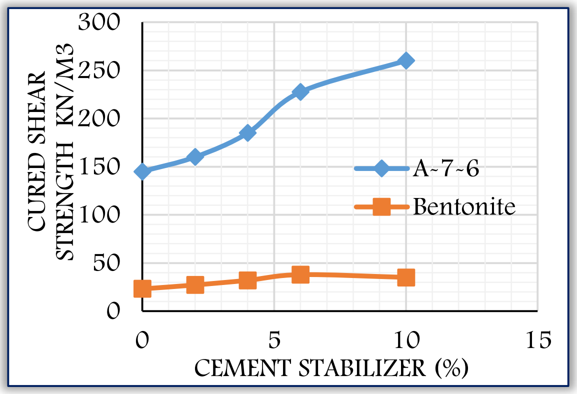

Figure 7: Variation of Shear Strength with Cement Content (cured soil cement)

Figure 2 shows the compaction characteristic curves for stabilized A-7-6 soil with cement while Figure 3 shows the same curve for bentonite. In the two curves, there is a continuous increase in the maximum dry density (MDD) and also a continuous increase in optimum moisture content with increase in cement content. These increases are clearly shown in Figures 4 and 5.

Figures 6 and 7 show the undrained shear strength of the soils. These are represented in Figure6 by the results of soaked CBR with increased cement content while Figure7 shows the results of shear strength (c) which is equal to half the unconfined compressive strength (q_u /2). The results show very significant increases in the shear strength with increases in cement content for the A-7–6 lateritic soil while very small increases are recorded for the bentonite.

The increase in MDD in Figures 2, 3 and 5 is due to two main reasons; the first being that cement because of its very fine grain sizes is able to fill any void in the soil to increase its denseness and the second reason is that the specific gravity of cement is 3.15 while that of A-7- 6 soil is 2.68 and bentonite is 2.38. Thus, any increases in cement content (with higher specific gravity) will automatically increase its MDD in the two soils. Figure4 shows that with increased values of cement, values of optimum moisture content (OMC) increased for both soils. The increase in optimum moisture content is due to more moisture required for effective hydration of cement (Ola, 1975) and (Osinubi, 1999).

The increase in shear strength in Figures 6 and 7 is due to cement stabilization mechanism. Cement hydrates when water is added, producing cementitious compounds independently of the soil. These products are calcium silicate hydrates, calcium aluminate hydrates and hydrated lime. The first two products constitute the major cementitious components, whereas the lime is deposited as a separate crystalline solid phase. The increase in strength is due to the development of cementitious linkages between these hydration products and soil particles. The lime released during the hydration of the cement may react with any pozzolanic material (e.g. clay present in the soil) to form a secondary cementitious material which also contributes to inter-particle bonding. Thus a sizable fraction of the cementitious material formed in soil-cement is contributed by the soil itself; Ola (1983), Moh (1962)

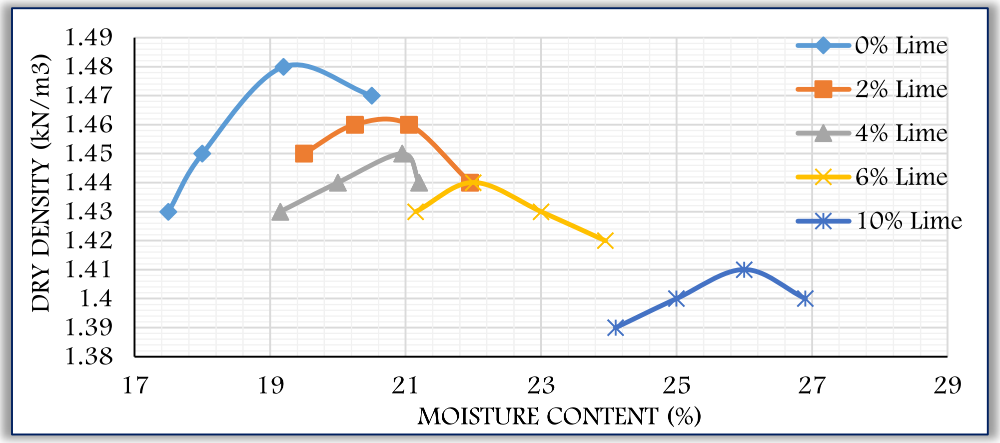

Figure 8: Compaction Characteristic Curves for Stabilized A-7-6 Soil with Lime

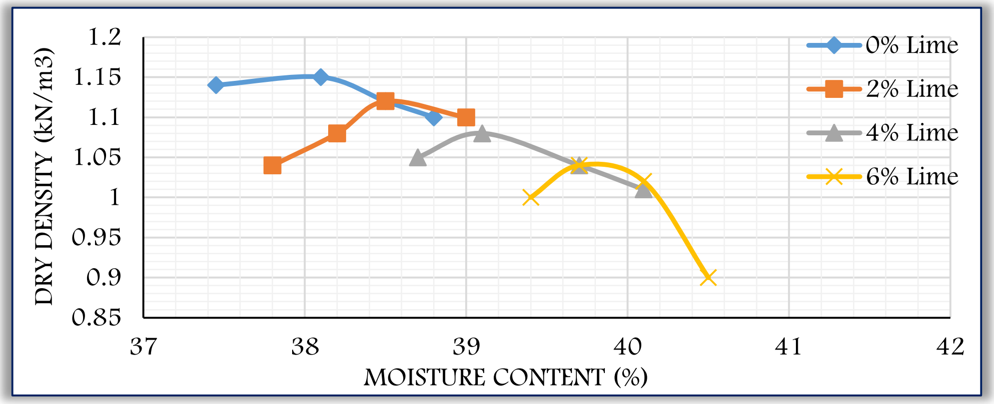

Figure 9: Compaction Characteristic Curve for Stabilized Bentonite with Lime

Figure 8 shows the compaction characteristic curves for stabilized A-7-6 soil with lime while Figure9 shows the same curve for bentonite. In the two curves, there is a continuous decrease in the maximum dry density (MDD) and a continuous increase in optimum moisture content with increase in lime content. These behaviours are clearly shown in Figures 10 and 11. Figures 12 and 13 show the undrained shear strength of the soils. These are presented in Figure12 by the results of soaked CBR with increased lime content while Figure13 shows the results of shear strength (c). The results show very significant increases in the shear strength with increases in lime content for the A-7– 6 lateritic soil while marginal increases are recorded for the bentonite.

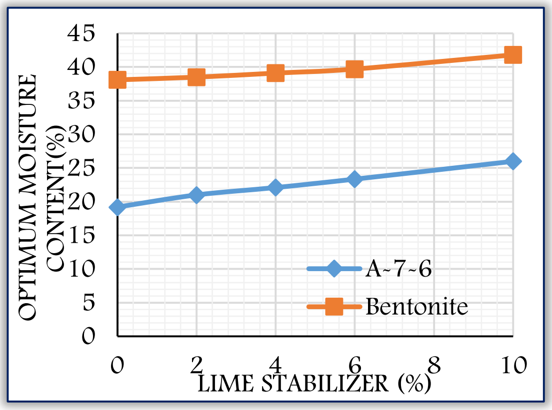

Figure 10: Variation of Optimum Moisture Content (OMC) with Lime Content

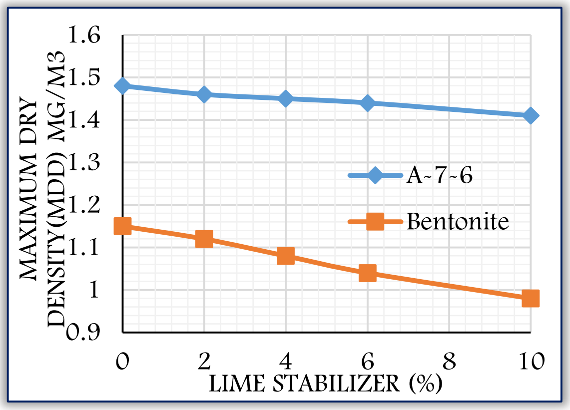

Figure 11: Variation of MDD with Lime Content

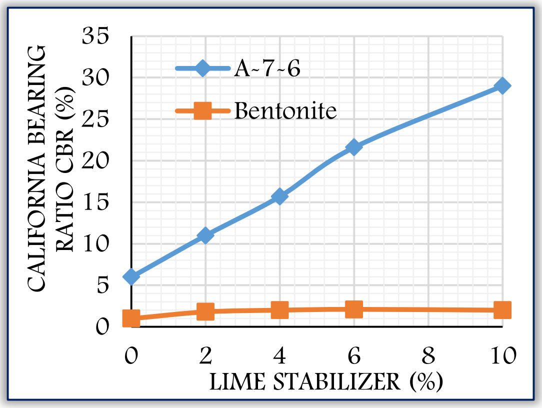

Figure 12: Variation of Soaked CBR with Lime Content

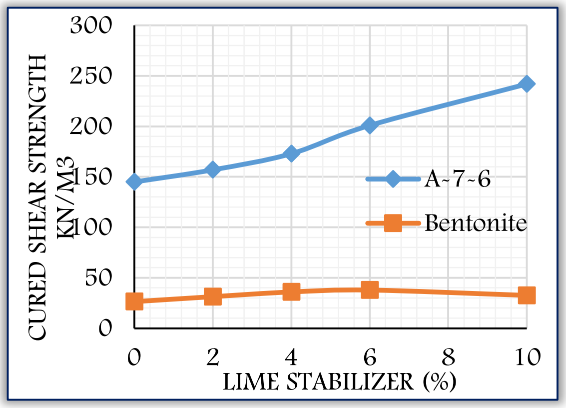

Figure 13: Variation of Shear Strength with Lime Content (cured soil lime)

The decrease in MDD in Figures 8, 9 and 11 is due to the fact that the specific gravity of lime is 2.2 while that of A-7- 6 soil is 2.68 and bentonite is 2.38 . Thus, any increase in lime content (with lower specific gravity) will automatically decrease its MDD in the two soils. Figure10 shows that with increased values of lime, values of optimum moisture content (OMC) increased for both soils. The increase in optimum moisture content is due to more moisture required for cation exchange and pozzolanic reaction of lime. The increase in shear strength in Figures12 and 13 is due to lime stabilization mechanism. The lime reacts with any pozzolanic material (e.g. clay present in the soil) to form a secondary cementitious material which contributes to inter-particle bonding.

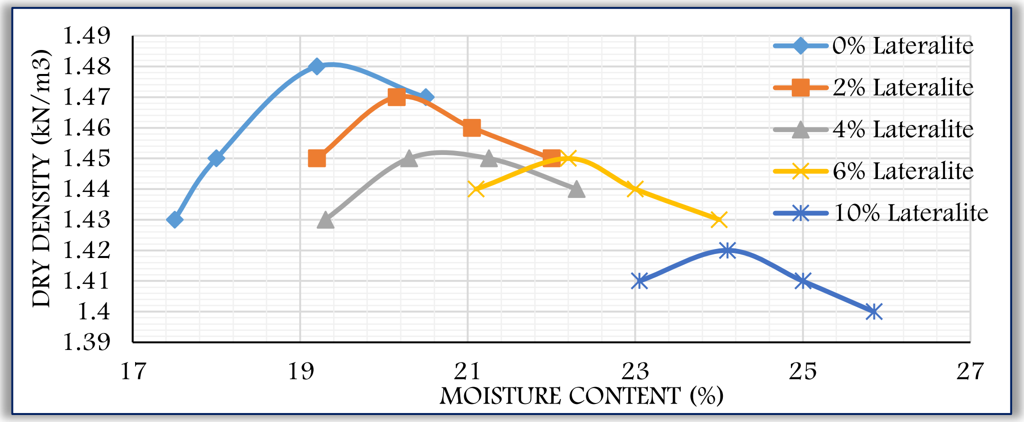

Figure 14: Compaction Characteristic Curves for Stabilized A-7-6 Soil with Lateralite

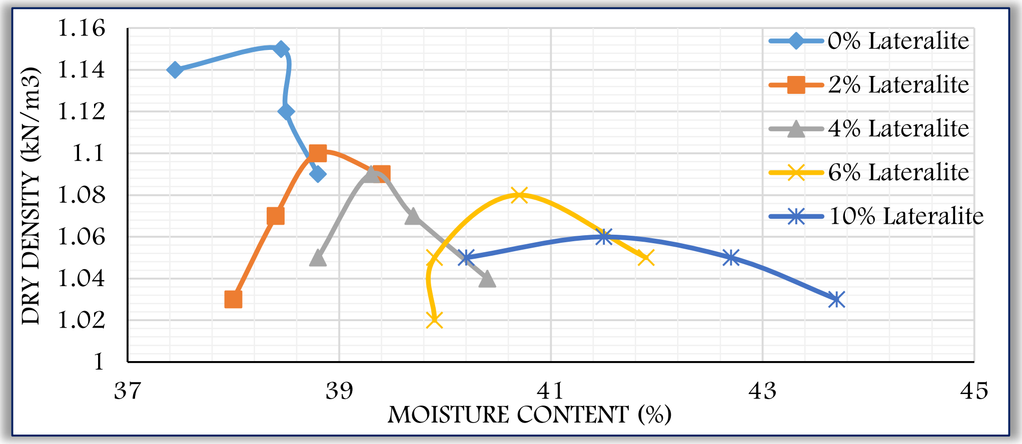

Figure 15: Compaction Characteristic Curves for Stabilized Bentonite with Lateralite

Figure14 shows the compaction characteristic curves for stabilized A-7-6 soil with lateralite while Figure15 shows the same curve for bentonite. In the two curves, there is a continuous decrease in the maximum dry density (MDD) and a continuous increase in optimum moisture content with increase in lateralite content. These behaviours are clearly shown in Figures 16 and 17. Figures 18 and 19 show the undrained shear strength of the soils. Figure18 shows the results of soaked CBR with increased lateralite content while Figure19 shows the results of shear strength (c). The results show very significant increases in the shear strength with increases in lateralite content for the A-7– 6 lateritic soil while marginal increases are recorded for the bentonite.

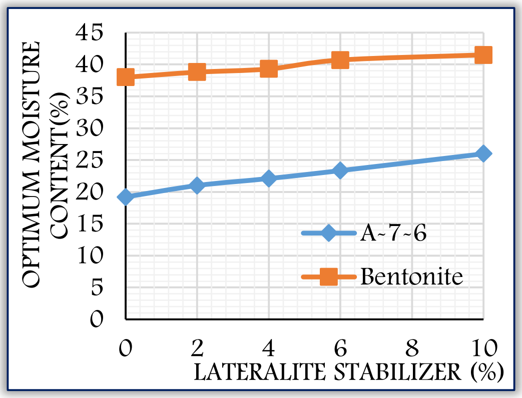

Figure 16: Variation of Optimum Moisture Content (OMC) with Lateralite Content

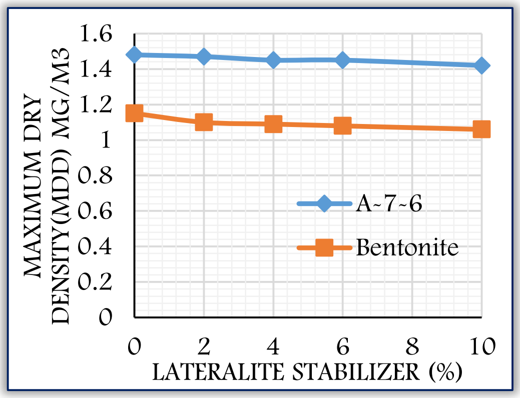

Figure 17: Variation of MDD with Lateralite Content

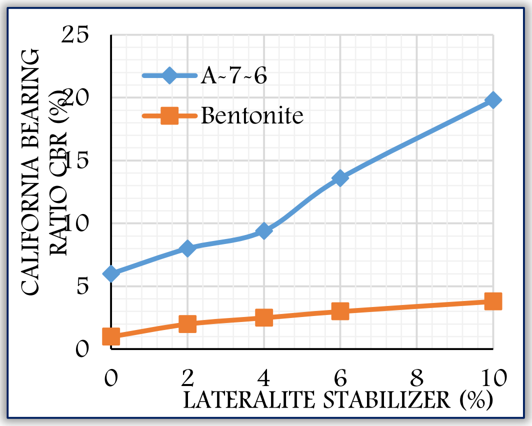

Figure 18: Variation of soaked CBR with Lateralite Content

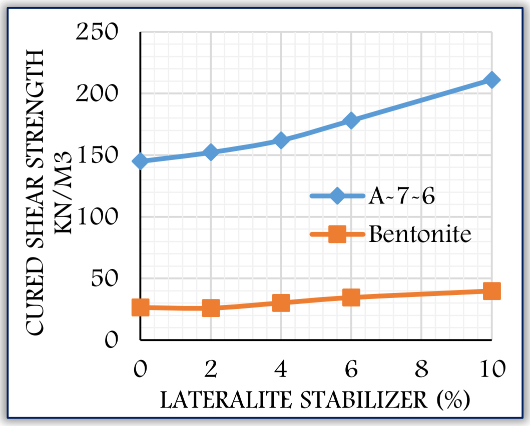

Figure 19: Variation of Shear Strength with Lateralite Content (cured soil lateralite)

The decrease in MDD in Figures 14, 15 and 17 is due to the fact that the specific gravity of lateralite is 2.45 while that of A-7- 6 soil is 2.68 and bentonite is 2.38. Thus, any increase in lateralite content (with lower specific gravity) will automatically decrease its MDD in the A-7-6 soil. The specific gravity of lateralite is about the same as that of bentonite; however, according to Kumar et al.,(2014), the decrease in the dry unit weight is attributed to the fact that lateralite reacts quickly with the bentonite resulting in a base exchange aggregate and flocculation, which leads to an increase in the void ratio of the mixture and leads to a decrease in the dry unit weight of the bentonite – lateralite mixture.

Figure16 shows that with increased values of lateralite, values of optimum moisture content (OMC) increased for both soils. The increase in optimum moisture content is due to more moisture required for cation exchange and pozzolanic reaction of lateralite. The increase in shear strength in Figures18 and 19 is due to adequate hydration of cementitious properties of lateralite which contributes to inter particle bonding.

Table 3 presents the Comparison in the Values of the Stabilizers on the two selected Soils.

Table 3. Comparing the Values of the Additives on the two Selected Soils

	% Stabilizer	Cement	A-7-6 SOIL		Cement	BENTONITE	
			Lime	Lateralite		Lime	Lateralite
CBR SOAKED (%)	0	6	6	6	1	1	1
CBR UNSOAKED (%)	0	8	8	8	3	3	3
c (kN/m2)	0	145	145	145	23.3	23.3	23.3
CBR SOAKED (%)	2	17	11	8	2	1.8	2
CBR UNSOAKED (%)	2	28.5	22.4	14.6	5	4.2	7.6
c (kN/m2)	2	160	157	152.5	27.3	26.4	25.9
CBR SOAKED (%)	4	20.5	15.7	9.4	2.1	2	2
CBR UNSOAKED (%)	4	40.2	35.8	26.2	6.5	5.4	7.6
c (kN/m2)	4	185	173	162	32	31.3	29
CBR SOAKED (%)	6	30.6	21.6	13.6	2.3	2.1	2
CBR UNSOAKED (%)	6	51.3	48.6	38.6	8.2	7.8	7.6
c (kN/m2)	6	227.5	201	178	37.8	35.9	31.4
CBR SOAKED (%)	10	38.8	29	19.8	2.1	2	2
CBR UNSOAKED (%)	10	65.8	62.8	48.8	8	7.6	7.6
c (kN/m2)	10	260	242	211	35	32.6	32.2

From the tests carried out on the A-7-6 lateritic soil sample and the bentonite, and the summary of the strength properties of the stabilized soils given in Table 3, the following observations can be made.

- A-7-6 lateritic soil was treated with lime, cement and lateralite respectively, stabilizing A-7-6 soil with cement showed improvement in strength values for soaked and unsoaked CBR. Values increased from 6% and 8% at natural state to 38.8% and 65.8% at 10% cement. Furthermore the shear strength increased from 145 kN/m^2 at natural state to 260 kN/m^2 for 10% cement after 7days curing. Stabilizing the A-7-6 soil with lime also showed improvement in strength values for soaked and unsoaked CBR which rose from 6% and 8% to 29.0% and 62.8% at 10% lime, the values for shear strength also increased to 242 kN/m^2 after 7days curing. The soaked and unsoaked CBR values after treating the A-7-6 soil with lateralite showed an appreciable increase from 6% and 8% at natural state to 19.8% to 48.8% at 10% lateralite. The shear strength values also increased from 145 kN/m^2 at natural state to 211 kN/m^2 for 10% cement after 7days curing.
- Bentonite was treated with lime, cement and lateralite respectively. Stabilizing bentonite with cement showed improvement in strength values for soaked and unsoaked CBR. Values increased from 1% and 3% at natural state to 2.1% and 8.0% at 10% cement. Furthermore shear strength increased from 23.3 kN/m^2 at natural state to 35 kN/m^2 for 10% cement after 7days curing. Stabilizing bentonite with lime also showed improvement in strength values for soaked and unsoaked CBR which rose from1% and 3% to 2.0% and 7.6% at 10% lime, the values for shear strength also increased from 23.3 kN/m^2 at natural state to 32.6 kN/m^2 at 10% lime after 7days curing. Lastly the soaked and unsoaked CBR values after treating bentonite with lateralite showed an appreciable increase from 1% and 3% at natural state to 2% and 6.8% at 10% lateralite. The shear strength values also increased from 23.3 kN/m^2 at natural state to 32.2 kN/m^2 at 10% lateralite after 7days curing.

5. CONCLUSIONS

Marginal improvement in strength value was recorded when stabilizing bentonite unlike in the case of the A-7-6 lateritic soil where appreciable improvement was recorded. It is quite clear that

In ALL the cases shown for the A-7-6 lateritic soil, cement stabilization had the best results and would be most effective in stabilizing this soil. It is followed by by lime stabilization and the lateralite stabilization was third. It is also clear that for the bentonite soil, there is no significant difference in the results of the three stabilizers. Therefore lateralite can substitute for cement or lime.

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